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# Farmers' agronomic practices in relation to the productivity of cacao, *Theobroma cacao* L. in the major growing regions of Uganda

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## Abstract

Despite being the 3rd most important foreign earner crop in Uganda, production of cacao is only 550 kg/ha of dry beans, compared to Côte d'Ivoire (800 kg/ha) and Malaysia (1,700 kg/ha), probably due to poor agronomic and management practices, among others. We therefore visited 116 cacao growing households located in the three major cacao growing regions of Uganda to assess agronomic and management practices carried out by farmers. A 50 x 50 m plot was demarcated in each household garden and 12 cacao trees were systematically sampled along two cross diagonal transects. We established the age, number of pods, level of plant and field management as well as spacing of cacao trees. Results showed that >50% of cacao trees were >20 years old, with an average of 13.1 pods per tree. Cacao trees were generally poorly managed and spaced at an average of 4.0 x 4.1m. Gardens were highly intercropped (94%) and under agroforestry (99.9%), with (89.7%) and coffee (51.7%), and, *Maesopsis eminii* (32.1%), being most prevalent, respectively. More than half of the gardens were moderately to highly weeded or mulched but, only 2.6 and 12.9% of the gardens had cover crops and trenches, respectively. Furthermore, the number of pods increased significantly ($p \leq 0.05$) with pruning and stumping but, decreased with age and plant density, though not significantly ($p \geq 0.05$). This information forms a baseline for developing technologies and innovations for managing these agronomic and management stresses as well as the National Cacao Research Agenda and Strategic Plan for Uganda.

**Keywords:** Age; Agroforestry; Intercropping; *Maesopsis-Eminii*; Mulching; Number-Of-Pods; Pruning; Spacing; Stumping; Weeding

## 1. Introduction

Cacao (*Theobroma cacao* L) is a tropical crop that belongs to the Malvaceae family and the genus Theobroma [1] and is commonly known as cacao in case of plant or cocoa when referring to products [2, 3]. The crop is native to the tropical and humid forests of the Amazon and Central America [4, 5]. Cacao is extensively cultivated for its beans, which are the primary raw material for various cocoa products particularly, chocolate, cocoa powder, and cocoa butter [6]. Cacao is one of the major agricultural commodities that are traded and consumed around the world because it provides economic benefits to producing countries, smallholder farmers cultivating the crop, and the confectionery industry by providing key raw materials [7]. Approximately, 5 to 6 million farmers grow the crop worldwide [8] and it is estimated that around 40 to 50 million people rely on its production for their livelihood [9]. Annually above 5 million tons of cocoa beans are produced worldwide, around 75% in Africa, mainly in Ivory Coast and Ghana [10].

In Uganda, cacao production has been rapidly increasing in the past 20 years [11], as shown by exports growing from

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2,130 metric tons (MT) of commercial cocoa in the year 2001, to 35,000 MT in the year 2020 [12]. This trend is expected to continue due to the country's suitable climatic conditions for cacao cultivation [13] and increasing governmental promotion efforts [14]. Due to its contribution to export earnings, cacao is one of the 10 commodities selected by the Fourth National Development Plan (NDPIV) to foster a sustainable agro-industrialization agenda in Uganda [15]. The crop is grown by 15,000-20,000 households on an estimated 20,000 ha of land with major production areas being in mid-western, central and mid-eastern regions [14, 16]. Cacao successfully grows in Uganda due to good soil and climatic conditions for cacao [17]. Furthermore, being a perennial tree crop, cacao plays many other ecological roles including atmospheric carbon sequestration and conservation of useful fauna such as pollinators and decomposers [18]. It is, therefore, a key crop in eradicating extreme poverty as well as ensuring environmental sustainability [19].

Despite its immense economic potential, cacao yields at farm level in Uganda are only 550 kg/ha of dry beans [20], compared to what is produced in countries like Côte d'Ivoire (800 kg/ha) and Malaysia (1700 kg/ha) [21]. These relatively low yields are due to a combination of factors including poor agronomic and management practices for the abiotic and biotic stresses [22]. In addition, most farmers are managing these stresses without being guided by research findings [23]. Moreso, the country lacks the socioeconomic frameworks for the cocoa sub-sector such as Cocoa Policy, National Cocoa Strategic Plan and National Cocoa Research Agenda [24].

Basing on this backdrop, we therefore hypothesized that the low cacao productivity in Uganda is attributable to sub-optimal agronomic practices. As such, we conducted a field assessment with an aim of describing the agronomic characteristics of the cacao in the three (3) major cacao growing regions of Uganda. Specifically, we ascertained the agronomic practices: (i) at plant-level; (ii) at plot-level; and, (iii) in relation to cacao productivity. This information serves as a baseline for developing innovations and technologies for managing these stresses. It will also inform the necessary socio-economic frameworks for guiding the cocoa sub-sector in Uganda.

## 2. Material and methods

### 2.1. Study area

The study was conducted in Uganda, located in East Africa and lies astride the Equator, between latitudes 4°12'N and 1°29'S and longitudes 29°34'W and 35°0'E. Temperatures are in the range of 15–30°C. A total of 11 districts were surveyed in the three major cacao growing regions of Uganda [25, 26], including: central (Mpigi, Kayunga, Mukono and Buikwe districts), mid-eastern region (Jinja, Kamuli, Luuka and Mayuge districts) and mid-western region (Bundibugyo, Kibale and Hoima district) (Fig. 1).

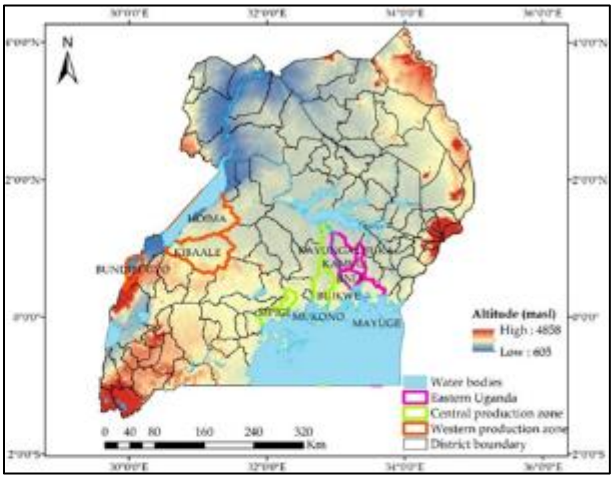


**Figure 1** Map showing the survey districts in the major cacao growing regions of Uganda

### 2.2. Data collection

Two (2) sub-counties were randomly selected in each of the above-mentioned districts and 116 cacao gardens (36 in central, 35 in mid-eastern and 45 in mid-western regions) selected. In each selected cacao garden, a plot measuring 50 x 50m was demarcated. At plant level, 12 cacao trees were systematically sampled along two cross diagonal transects running the full length of the demarcated plot (one running from left to right and the other one from right to left). In each diagonal, 6 cacao trees were selected every after 14 m for data collection. The age of each of the sampled cacao tree was estimated and all the pods counted and recorded. The sampled cacao tree was further scored for the level of pruning, de-suckering and stumping [27] at a scale of 0-3, where: 0= not practicing, 1=low, 2=moderate, and, 3=high.

At plot level, the spacing of the 12 sampled cacao plants was established by measuring the distance between the sampled cacao tree to the trees neighboring it – infront , behind, left and right, and then taking the average [28]. In addition, other crops in the cacao gardens were established. Then, the number of trees and shrubs (at least 1.5 m tall) apart from cacao was established and identified to species levels (where possible) in either English or scientific name [29]. Furthermore, the level of weeding, mulching, use of cover crops and trenches was also scored as: not practiced, low, medium or high.

### 2.3. Data analysis

Descriptive and summary statistics such as means, frequencies, variances and ranges were used to analyze the data. In addition, correlation and regression analyses were performed to establish the relationship between the number of pods and the level of application of the different agronomic practices (pruning, stumping, de-suckering, age and plant density) on cacao in the three major cacao growing regions of Uganda. Statistical Analysis System (SAS) software [30] was used to perform all the analyses.

## 3. Results and discussion

### 3.1. Plant level practices

#### *3.1.1. Age of the cacao trees*

Having knowledge of the age of cacao trees is vital as it has been reported to be one of the main factors that influence the yield [31]. Results of this study showed that on average, more than half of the cacao trees we surveyed were more than 20 years of age, particularly in mid-western Uganda where 85.6% of the cacao trees were in this category (Table 1), implying that most of the cacao trees in Uganda are relatively old. This could be attributed to the fact that historically, Bundibugyo area is one of the pioneer areas where cacao was established because of its elevation, slope and rainfall that favored growth of the crop [26, 32]. Similar results have been reported in Uganda [12] and in other countries such as Ivory Coast [33], Cameroon [34], and, East Java [35]. The old age of the cacao plants and gardens is one of the major causes of low yields in most of the cacao growing countries in Africa [22, 31, 36, 37, 38]. This is due to the biological lags inherent in perennial crops [39].

Generally, a cacao tree begins producing pods at about three years after planting, reaching full bearing capacity around the age of 10-20 years, and their output starts to diminish gradually thereafter due to loss of flower cushions and nutrient mining [40, 41, 42, 43]. In addition, old age of cacao trees has been associated with increase in incidence and damage of pests and diseases [44], such as the witches' broom [45, 46].

Therefore, the existing old trees in farmers' gardens, particularly in mid-western Uganda need to be rejuvenated and rehabilitated [47] or the cacao gardens need to be replanted [31, 48] so as to recover the yield performance [39, 49]. However, research shows that some farmers may be reluctant to rehabilitate their cacao trees or replant their cacao gardens if the trees can still bear some cacao pods and therefore provide some income [38].

**Table 1** Age ranges of cacao trees surveyed in the three major cacao growing regions of Uganda

| Region | Mean age (years) | | | | |
|---|---|---|---|---|---|
| | <5 | 6-10 | 11-15 | 16-20 | >20 |
| Central | 25.0 | 25.0 | 8.1 | 2.8 | 39.1 |
| Mid-eastern | 0.2 | 26.2 | 28.3 | 21.0 | 24.3 |
| Mid-western | 2.8 | 8.0 | 3.7 | 0.0 | 85.6 |
| Overall mean | 8.9 | 18.8 | 12.5 | 7.2 | 52.7 |

#### *3.1.2. Number of pods per cacao tree*

Determining the number of pods on a tree is one of the methods that is usually used to forecast cacao yields [50, 51]. Our results showed that the overall mean number of cacao pods recorded was 13.1, with the highest (23.1 pods) being recorded in central and lowest (6.8 pods) in the mid-western region (Fig. 2). This could in part due to fact that cacao trees in the mid-western were generally older than in other regions [38, 39]. Similar to our finding, [25] observed that 78-92% of the local cacao varieties were producing less than 20 pods per tree in Damba Island, Mukono district, Uganda. Low numbers of cacao pods per plant have also been reported elsewhere [52, 53].

However, our overall mean number of pods is far less than the recommended good yield of 20 or more pods per tree [54]. The number of pods produced on a cacao tree depends on a number of interplaying factors such as age of the tree, genetics, environmental, pests and diseases, as well as the agronomic practices [e.g. 51, 55, 56, 57]. Nevertheless, pod count per tree is considered as one of the methods of determining when to renew cacao trees and [49] recommends that a tree having 14 or less pods should be renewed. This implies that the cacao trees in the mid-western and mid-eastern regions need to be renewed so as to rejuvenate their productivity [49, 58].

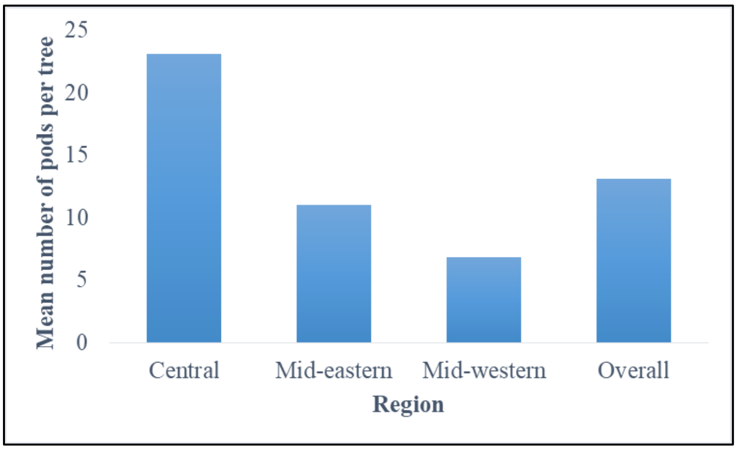


**Figure 2** Mean number of pods recorded on cacao trees surveyed in the three major cacao growing regions of Uganda

*3.1.3. Level of pruning of the cacao trees*

Pruning is the removal of unwanted branches from a cacao tree [59]. This modifies the leaf area and therefore affect the vegetative, reproductive, and production variables [60]. Overall, most (37.7%) of the cacao plants were not pruned across all the three study areas, with the mid-western region having the highest (70%) number of unpruned cacao trees (Table 2). This finding is in agreement with [19] who observed that 80% of the cacao plants in Hoima district which is located in mid-western Uganda, were not pruned. Similarly, a baseline study conducted in Côte d'Ivoire and Nigeria showed that only 1.8 and 16.6% of the cacao producers, respectively, reported that they had pruned their cacao trees [61]. Low levels of pruning of cacao plants in the mid-western region could in part be attributed to the fact that in this region, majority of the cacao trees were generally old (Table 1), implying that farmers might be experiencing challenges in accessing the tree canopies in order to prune off the old or excess branches [62]. In addition, farmers might be having limited technical knowledge and capacity to execute this practice [63], though, some of them might prefer to leave some chupons on the main branches thinking that they will produce more pods [64, 65, 66]. But also, famers in Ecuador do not usually prune tall and old cacao trees because the practice is costly (US$1 per tree) and the yield gain is marginal, making it uneconomical [67].

However, our results showed that more than 70% of the cacao trees sampled in central Uganda were highly pruned (Table 2). This finding is supported by observations made elsewhere [68, 69]. This could be in part be due to fact that cacao in central Uganda is generally younger than in the mid-western region (Table 1) and therefore easier to prune [70]. Nevertheless, pruning, which is the removal of unwanted branches (chupons or water threats/shoots) from a cacao tree [71, 72, 73, 74], reduces crowding in cacao plantations [75] by maintaining the proper shape of the cacao tree, thus, facilitating the crop management tasks [68]. Pruning also allows sunlight to penetrate through the cacao canopy, creating a warm condition which induces flowering and pods production [76. 77, 78], thus, enhancing yields [60]. It is also considered an important practice for managing cacao pests and diseases [79] such as frosty pod rot, *Moniliophthor aroreri* [68] and black pod, *Phytoptora palmivora* [80]. Pruning should therefore be considered as one of the components of a cost-effective, locally realizable pest and disease management strategy that holds potential to reduce the amount of pesticides and the associated negative effects on human health and the environment [81].

**Table 2** Pruning levels of the cacao plants as observed in the three major cocoa growing regions of Uganda

| Region | Not pruned | Low | Moderate | High |
|---|---|---|---|---|
| Central | 8.8 | 4.6 | 9.0 | 77.5 |
| Mid-eastern | 23.3 | 53.8 | 21.2 | 1.7 |
| Mid-western | 72.0 | 7.0 | 4.3 | 16.7 |
| Overall mean | 37.7 | 20.4 | 10.8 | 31.0 |

*3.1.4. Level of de-suckering of the cacao trees*

De-suckering is the removal of excess suckers or chupons from the cacao plant [70] because they take away nutrients from productive branches [82]. Our results showed that all the cacao plants were either lowly de-suckered or not de-suckered at all. Overall, 54.8 and 45.2% of the sampled cacao trees were lowly de-suckered or not de-suckered, respectively, with the highest percentage (78.3%) of the trees which were not de-suckered being registered in the mid-western region (Table 3). Low level of sucker removal by farmers has also been reported in Hoima district, mid-western Uganda [19] and other cacao growing countries in Africa such as Nigeria [83]. This could in part be due to the fact that farmers might be having limited knowledge on the advantages as well as application and capacity to execute this agronomic practice [63]. But also, this practice might be time consuming and costly to the farmers, thus, making it uneconomical, though, it is commonly done in other cacao growing countries in Latin America, particularly, Ecuador and Brazil [67]. A cacao tree is usually maintained as a single stem by continuously removing all the other suckers (chupons) to prevent development of subsequent jorquettes and restricting further vertical growth [84]. In addition, this practice is one of the most commonly used cultural method for managing pests and diseases in cacao systems [85]. Research and extension should therefore encourage farmers to continuously remove these suckers or chupons from their cacao trees [86, 87].

**Table 3** De-suckering levels of the cacao plants as observed in the three major cacao growing regions of Uganda

| Region | Not de-suckered | Low |
|---|---|---|
| Central | 13.9 | 86.1 |
| Mid-eastern | 34.8 | 65.2 |
| Mid-western | 78.3 | 21.7 |
| Overall mean | 45.2 | 54.8 |

*3.1.5. Level of stumping or coppicing the cacao trees*

Stumping or coppicing is the complete removal of the majority of the main stem of a cacao tree to encourage the regeneration of the canopy by chupon growth as well as regulating the crown shape and tree size [34, 51, 88, 89, 90]. Results of our study showed that none of the cacao plants sampled in the mid-eastern and only 3.6% of those sampled in mid-western had been stumped (Fig. 3). Our finding is in line with earlier study conducted by [91] in Ondo State, Nigeria which showed that only 1% of the farmers they interviewed has fully integrated coppicing in their cacao rehabilitation programs. Similarly, low levels of adoption by farmers of the coppicing as a technique for rehabilitating cacao has been reported elsewhere [e.g. 90, 92, 93, 94]. This low level of stumping observed in the mid-western and mid-eastern regions could in part be due to the fact that farmers might be having limited knowledge on the advantages as well as the application and capacity to execute this agronomic practice [63]. In addition, stumping or coppicing might be time consuming and costly, and, therefore, the farmers do not realize the economic gain in terms of yield [67].

Contrary, 87% of the cacao trees we sampled in the central region had been stumped (Fig. 3). Similarly, [95] reported that 70.1% of the farmers they interviewed in Boki Local Government Area, Cross River State, Nigeria had knowledge of coppicing as a technique for rehabilitating old cacao trees. The high level of stumping observed in the central region could in part due to the fact that cacao trees in this region are generally young (Table 1) and therefore easier to be stumped [96]. Nevertheless, stumping or coppicing improves light penetration, stimulates the development of new buds, removes undesirable branches that compete for nutrients with productive branches, reduces pests and diseases, and enhances nutrient availability, ultimately boosting flowering and pod production [e.g. 56, 60, 76, 77, 97, 98]. This enhance yields and productivity of cacao [e.g. 99, 100, 101, 102]. There is therefore a need to sensitize the cacao farmers on rejuvenation and rehabilitation of their farms to increase been yield which will improve their standard of living and poverty reduction [63, 102].

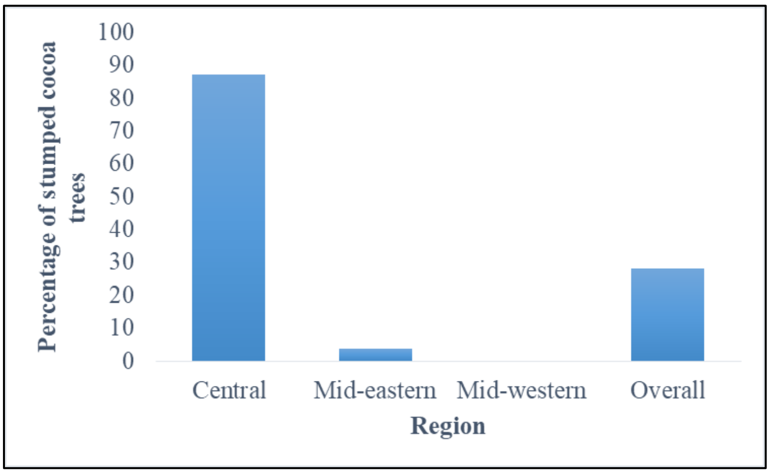


**Figure 3** The percentage of trees stumped as observed in the three major cacao growing regions of Uganda

### 3.2. Plot level practices

#### *3.2.1. Spacing of the cacao trees*

In cacao, spacing configurations is important in maximizing yield and bean characteristics [103]. The optimum spacing between trees is the planting density which will give the greatest economic return per unit area of land [83]. Generally, the overall spacing between the sampled cacao trees (4.0 x 4.1 m) (Table 4) was bigger than the recommended spacing of 3 x 3 m in most of the cacao growing countries including Uganda [e.g. 17, 45, 83, 103, 104, 105]. This could in part be due to the fact that farmers may be lacking the technical guidance on the optimal spacing regime for maximizing profits [28], but also some of the cacao trees might have been lost due to pests and diseases [106].

Literature shows that irregular spacing and density of cacao trees are some of the main causes of low productivity of cacao in Africa [106] and in cacao, spacing configurations is important in maximizing yield and bean characteristics [103]. However, studies conducted in other countries have demonstrated superiority of high density population over the traditional low density plantings in the early years of production [45, 83. 107, 108]. Research in Uganda should therefore explore this possibility of a high planting density system during the first few years of establishment while the trees surpluses be eliminated once the plants' canopy spread are becoming too interwoven [83].

**Table 4** Cacao tree spacing observed in the three major cocoa growing regions of Uganda

| Region | Average spacing (m) |
|---|---|
| Central | 3.5x3.8 |
| Mid-eastern | 4.2x4.4 |
| Mid-western | 4.2x4.0 |
| Overall mean | 4.0x4.1 |

#### *3.2.2. Intercropping in cacao gardens*

Cacao intercropping is the practice of growing other crops and trees in the same area as cacao trees [109]. Our results showed that majority (94%) of the cacao gardens sampled in the three cacao growing regions of Uganda were intercropped (Table 5). This finding agrees with [110] who observed that over 90% of the farmers interviewed in Tanzania had intercropped their cacao with other plant species. Similarly, [111] observed that almost all the farmers he interviewed in Nigeria had intercropped their cacao with other crops with only less 1% of the farms having it as a monocrop. This emphasizes the importance farmers attach to intercropping their cacao with food and cash crops to meet both food security and income needs [67, 112].

**Table 5** Percentage of cacao gardens that had intercrops in the major cocoa growing regions of Uganda

| Region | Not intercropped | Lowly | Moderately | Highly |
|---|---|---|---|---|
| Central | 2.8 | 27.8 | 41.7 | 27.8 |
| Mid-eastern | 5.7 | 48.6 | 45.7 | 0.0 |
| Mid-western | 8.9 | 42.2 | 20.0 | 28.9 |
| Overall mean | 6.0 | 39.7 | 34.5 | 19.8 |

Results of this study further showed that overall, the main intercrops in cacao gardens were: bananas (89.7%) and coffee (51.7%) (Table 6). This finding is in agreement with earlier studies which reported that 92.3% of the farmers in Bendel, Ogun and Ondo states [111] and 71.1% in Oyo State of Nigeria [113], 95.1% in Mexico [113] and >85% in Tanzania [110] had intercropped their cacao with bananas. In addition, 41.0% of the farmers sampled in Bendel, Ogun, Ondo and Oyo States of Nigeria had also intercropped their cacao with coffee [111]. However, intercropping cacao and coffee might present a challenge because they share some pests, particularly, the notorious black coffee twig borer (BCTB), *Xylosandrus compactus* (Eichhoff) (Coleoptera: Curculionidae: Scolytinae) [19, 114. 115, 116, 117].

Furthermore, cassava was prominently observed as an intercrop in the central region (66.7%) (Table 6), agreeing with studies in Bendel, Ogun, Ondo and Oyo States as well as Osun State, Nigeria which showed that 51.3 and 39.2% of the farmers respectively, had intercropped their cacao with cassava [111, 118]. Farmers practice intercropping in order to maximize the available space to produce cacao for cash and other crops such as cassava, yams, beans for food security in their households [67, 112]. Intercropping can therefore give rise to substantial increases in yields because the component crops complement each other and make better use of environmental resources than when grown separately [119, 120]. In addition to being sources of food and cash for the households, bananas and cassava also provide shade for young cacao trees during plantation establishment [17, 113, 121, 122]. This is an effective strategy to maximize farmland utilization [121]. All in all, intercropping in cacao should be properly designed to take maximum advantage of the potential for complementarity in order to avoid or reduce completion for nutrients, light, moisture, space as well as promotion of pests and disease [123].

**Table 6** Percentage of the main intercrops observed in the three major cacao growing regions of Uganda

| Region | Bananas | Coffee | Cassava | Coco yams | Vanilla |
|---|---|---|---|---|---|
| Central | 97.2 | 27.8 | 66.7 | 47.2 | 16.7 |
| Mid-eastern | 100.0 | 82.9 | 11.4 | 28.6 | 17.1 |
| Mid-western | 75.6 | 46.7 | 11.1 | 2.2 | 20.0 |
| Overall mean | 89.7 | 51.7 | 28.4 | 24.1 | 18.1 |

### *3.2.3. Cacao agroforestry systems*

Cacao (*Theobroma cacao*) is an understory plant [124, 125], cultivated under different cropping systems, from full-sun monocultures to multi-strata agroforestry systems [126]. Our results showed that 99.9% of the cacao gardens we sampled in the three major cacao growing region of Uganda had been inter-planted with other tree and shrub species (Table 7). Similarly, studies conducted in the western and central cacao growing regions of Uganda showed that agroforestry was widely adopted in every district sampled by [12] and almost all surveyed farmers were aware of the concepts of agroforestry. Also, 86% of the farms surveyed in southwestern Cote d'Ivoire reported that they had embraced cacao agroforestry [127].

Table 7 further shows that majority (52%) of cacao gardens had moderate to high levels of canopy cover, agreeing with [19[ who reported that 40% of the cacao gardens sampled in Bundibugyo and Hoima districts of western Uganda had moderate level of canopy cover. Optimum cacao agroforestry has been reported to improve soil fertility and structure, enhance climate resilience, sequester carbon, reduce pests, weeds and diseases, modified light infiltration, enhance moisture availability, conserve biodiversity, enhance household incomes and livelihood as well as food and nutrition needs [e.g. 128, 129 130, 131, 132, 133]. In addition, agroforestry systems have been reported to increase yield of cacao [29, 134]. Government should therefore create economic incentives in order for farmers to retain shade trees on their cacao farms [135].

**Table 7** Percentage of cocoa gardens practicing agroforestry in the three major cacao growing regions of Uganda

| Region | Not practicing | Lowly | Moderately | Highly |
|---|---|---|---|---|
| Central | 0.0 | 47.2 | 38.9 | 13.9 |
| Mid-eastern | 0.0 | 47.1 | 47.1 | 5.9 |
| Mid-western | 2.2 | 46.7 | 20.0 | 31.1 |
| Overall mean | 0.9 | 47.0 | 33.9 | 18.3 |

Furthermore, a total of 46 different trees and shrub species belonging to 26 families were recorded in the cacao-based agroforestry systems (Table 8), agreeing with a number of earlier studies [136, 137, 139, 139]. The most prominent families were: Moraceae (9 species), Euphorbiaceae (4 species), and, Mimosaceae, Myrtaceae and Rutaceae (3 species each), agreeing with other research studies by [136, 140, 141]. The umbrella tree, *Maesopsis eminii* was the most frequently (32.1%) recorded shade tree species in the cacao systems of Uganda. This has also been observed in other cacao agroforestry systems of Uganda [12, 17, 19, 46] and elsewhere [142, 143]. The popularity of this tree species is attributed to its fast growth, readily available planting materials and ease of propagation [19]. In addition, the leaves of *M. eminii* decompose easily and it is compatible with most of the agricultural practices [144]. *M. eminii* also provides additional products such as timber and firewood [145]. However, this tree species has been reported to be one of the good alternate host plant species for the Black Coffee Twig Borer (BCTB), *Xylosandrus compactus* (Eichhoff) [146, 147]. *X. compactus* is currently one of the major insect pests infesting cacao in Uganda [146, 147, 148] and elsewhere [114, 115, 149]. This implies that the presence of *X. compactus* on *M. eminii* inter-planted in cacao presents a dilemma in managing this pest [147].

It should be noted that three (3) of the five (5) most common tree species recorded in the three major cacao growing regions of Uganda were edible fruit trees, in particular, jackfruit (10.8%), avocado (9.9%) and mango (7.2%) (Table 8). This finding supports other studies that have reported that edible fruit trees form a large proportion of tree species recorded in cacao-based agroforestry systems [136, 138, 150, 151]. This implies that farmers plant and/or retain and maintain tree species in their cacao gardens for ecological, economic, and social reasons [152, 153, 154] as well as for food and nutrition [136, 138]. Since the cacao agroforestry systems are popular in all the cacao growing regions of Uganda, research should therefore be geared towards identifying the most appropriate agroforestry tree species (including fruit trees) and spacing regimes which will not compromise cacao yields [134, 155].

**Table 8** Diversity of non-cocoa tree and shrub species in the 50 x 50 m transect of cacao agroforestry in the three major cacao growing regions of Uganda

| English name | Botanical name | Family | Region | | | |
|---|---|---|---|---|---|---|
| | | | Central | Eastern | Western | Total |
| Umbrella tree | *Maesopsis eminii* | Rhamnaceae | 41.3 | 24.8 | 32.5 | 32.1 |
| Jackfruit | *Artocarpus heterophyllus* | Moraceae | 5.4 | 12.9 | 13.3 | 10.8 |
| Avocado | *Persea Americana* | Lauraceae | 9.5 | 11.9 | 7.8 | 9.9 |
| Markamia | *Markhamia lutea* | Bignoniaceae | 5.7 | 8.8 | 11.0 | 8.6 |
| Mango | *Mangifera indica* | Anacardiaceae | 6.8 | 7.6 | 7.0 | 7.2 |
| Fig tree | *Ficus natalensis* | Moraceae | 6.3 | 3.1 | 4.3 | 4.4 |
| Paw paw | *Carica papaya* | Caricaceae | 4.6 | 0.0 | 4.5 | 3.9 |
| African teak: | *Milicia excels* | Moraceae | 1.9 | 5.7 | 1.5 | 3.3 |
| Barbados nut | *Jatropha curcas* | Eupborbiaceae | 0.3 | 2.9 | 1.8 | 1.8 |
| Guava | *Psidium guajava* | Myrtaceae | 3.0 | 1.8 | 0.3 | 1.7 |
| African elemi, | *Canarium schweinfurthii* | Burseraceae | 1.4 | 2.1 | 0.3 | 1.3 |
| Silk tree | *Albizia chinensis* | Mimosaceae | 4.3 | 0.0 | 0.0 | 1.3 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Orange | *Citrus sinensis* | Rutaceae | 1.1 | 2.5 | 0.0 | 1.3 |
| Lightwood | *Albizia coriaria* | Mimosaceae | 1.9 | 1.0 | 0.5 | 1.1 |
| African tulip tree | *Spathodea campanulata* | Bignoniaceae | 0.5 | 0.6 | 1.3 | 0.8 |
| Golden wonder tree | *Senna spectabilis* | Caesalpiniaceae | 0.5 | 0.2 | 1.8 | 0.8 |
| Indian rubber tree | *Ficus elastic* | Moraceae | 0.8 | 0.0 | 0.3 | 0.7 |
| Lemon | *Citrus limon* | Rutaceae | 0.0 | 1.8 | 0.0 | 0.7 |
| Bitter leaf | *Vernonia amygdalina* | Compositae | 0.3 | 0.6 | 1.0 | 0.6 |
| Large-leaved Albizia | *Albizia grandibracteata* | Mimosaceae | 0.0 | 0.0 | 2.0 | 0.6 |
| Upas tree | *Antiaris toxicaria* | Moraceae | 0.8 | 0.6 | 0.3 | 0.6 |
| Caribbean pine | *Pinus caribaea* | Pinaceae | 0.0 | 1.0 | 0.5 | 0.6 |
| Horseradish tree | *Moringa oleifera* | Moringaceae | 0.0 | 0.6 | 0.8 | 0.5 |
| Castor bean. | *Ricinus communis* | Eupborbiaceae | 0.3 | 0.0 | 1.0 | 0.4 |
| Pheasant-berry | *Margaritaria discoideus* | Eupborbiaceae | 0.0 | 0.2 | 1.0 | 0.4 |
| White mulberry | *Morus alba* | Moraceae | 1.4 | 0.0 | 0.0 | 0.4 |
| Java plum | *Syzygium cuminii* | Myrtaceae | 0.5 | 0.6 | 0.0 | 0.4 |
| Sandpaper tree, | *Ficus exasperate* | Moraceae | 0.5 | 0.0 | 0.5 | 0.3 |
| Mucus Fig | *Ficus mucuso* | Moraceae | 0.0 | 0.8 | 0.0 | 0.3 |
| Oil palm | *Elaeis guineensis* | Palmae | 0.0 | 0.0 | 1.0 | 0.3 |
| Silky oak | *Grevillea robusta* | Proteaceae | 0.0 | 0.6 | 0.0 | 0.3 |
| Mandarin orange | *Citrus reticulate* | Rutaceae | 0.0 | 0.8 | 0.0 | 0.3 |
| African grape. | *Pseudospondias microcarpa* | Anacardiaceae | 0.0 | 0.0 | 0.5 | 0.2 |
| Cheese wood | *Alstonia boonei* | Apocynaceae | 0.3 | 0.2 | 0.0 | 0.2 |
| Eucalyptus | *Eucalyptus grandis* | Myrtaceae | 0.0 | 0.2 | 0.3 | 0.2 |
| Red-hot poker tree | *Erythrina abyssinica* | Papilionaceae | 0.0 | 0.4 | 0.0 | 0.2 |
| African cherry | *Prunus Africana* | Rosaceae | 0.5 | 0.0 | 0.0 | 0.2 |
| Soursop | *Annona muricata* | Annonaceae | 0.0 | 0.2 | 0.0 | 0.1 |
| Parasol tree | *Polyscias fulva* | Araliaceae | 0.0 | 0.2 | 0.0 | 0.1 |
| Terminalia | *Terminalia glaucescens* | Combretaceae | 0.0 | 0.2 | 0.0 | 0.1 |
| Bitter leaf | *Vernonia auriculifera* | Compositae | 0.0 | 0.2 | 0.0 | 0.1 |
| Bush nightfighter | *Dracaena steudneri* | Dracaenaceae | 0.0 | 0.2 | 0.0 | 0.1 |
| Candlenut tree | *Aleurites moluccana* | Eupborbiaceae | 0.0 | 0.0 | 0.3 | 0.1 |
| Dragon's blood tree | *Harungana madagascariensis* | Guttiferae | 0.0 | 0.0 | 0.3 | 0.1 |
| Neem | *Azadirachta indica* | Meliaceae | 0.0 | 0.2 | 0.0 | 0.1 |
| Punjab tree | *Ficus ovate* | Moraceae | 0.0 | 0.2 | 0.0 | 0.1 |

### *3.2.4. Weeding*

Regular weeding is an important farm activity for the maintenance of cacao [156] and it improves the growth of crop [157, 158]. The majority of cacao gardens (79%) sampled in our study had been moderately to highly weeded (Table 9), implying that farmers generally weed their cacao gardens. This finding is in line with observations in a study conducted in the western region of Uganda that showed that 93.3% of the cacao gardens sampled had been moderately to highly weeded [19]. Similarly, 95 and 91% of the farmers in Ghana and Ivory Coast, respectively, reported that they weeded their cacao gardens [69]. Weeding is crucial in cacao cultivation, particularly during the early stages of development, to prevent them from competing with cacao trees for essential nutrients, space, moisture and light but, may also harbor pests and diseases [159]. Weeds have also been reported to cause a yield loss of 12-80% in cacao [160] but, this depends on the nature, intensity, stage and duration of crop competition with weeds [161]. Effective and timely weed control is therefore critical to obtaining the potential yield in cacao [162], though, the weeding effort depends on the maturity of the cacao plantation. It is very critical during the first 3 years of establishment of a cacao garden and decreases in the 4th to 5th year when thick canopy coverage and layer of cacao litter would have been built up [163].

**Table 9** The level of weeding (%) observed in the three major cacao growing regions of Uganda

| Region | Not weeded | Low | Medium | High |
|---|---|---|---|---|
| Central | 8.3 | 11.1 | 38.9 | 41.7 |
| Mid-eastern | 0.0 | 20.0 | 51.4 | 28.6 |
| Mid-western | 8.9 | 13.3 | 28.9 | 48.9 |
| Overall mean | 6.0 | 14.7 | 38.8 | 40.5 |

*3.2.5. Mulching*

Mulching has been reported to be one of the important factors determining the success of a cacao plantation business [164], particularly at establishment [165] and when the cacao is still at young stage [166]. Results of this study showed that overall, >60% of the cacao gardens sampled in the three major cacao growing regions of Uganda were moderately or highly mulched (Table 10). Our finding is in line with studies by [19], who observed that majority of the cacao gardens they sampled in the mid-western region of Uganda were moderately or highly mulched.

**Table 10** The level of mulching (%) observed in the three cacao growing regions of Uganda

| Region | No mulch | Low | Medium | High |
|---|---|---|---|---|
| Central | 11.1 | 47.2 | 36.1 | 5.6 |
| Mid-eastern | 0.0 | 20.6 | 52.9 | 26.5 |
| Mid-western | 2.2 | 33.3 | 37.8 | 26.7 |
| Overall mean | 4.3 | 33.9 | 41.7 | 20.0 |

However, the majority (93%) of these cacao gardens were self-mulched (Fig. 4). This finding is in line with results of a survey conducted by [19] in western Uganda cacao growing region that reported that more than 90% of the cacao gardens assessed were moderately to highly mulched. Similarly, [167] reported that more than half of the farmers they interviewed in Nigeria were mulching their cacao gardens. Cacao is relatively sensitive to water deficit [53, 168]. Mulching therefore, helps in conserving this soil moisture by preventing evaporation from the soil surface and reducing erosion from runoff [166]. Mulches also prevent growth of weeds [169] and at the same time can be a source of nutrients that enhance the health of the plant [170].

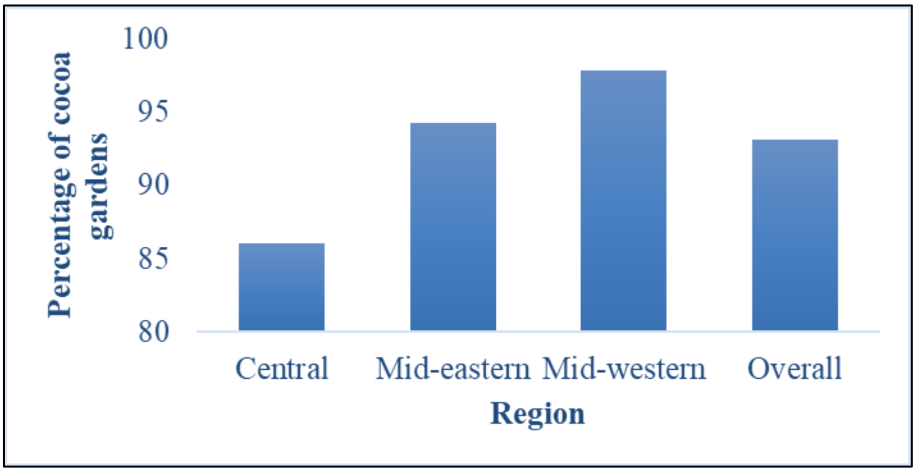


**Figure 4** Percentage of self-mulched cacao gardens in the three cacao growing regions of Uganda

### 3.3. Cover crops

Despite the benefits attached to cover crops [171], results of our study showed that overall, only 2.6% of the cacao gardens sampled in the three cacao growing regions of Uganda had cover crops (Table 11). This could in part be due to the knowledge gaps on the advantages of cover crops as well as detailed species and management recommendations to maximize ecosystem services and optimize the soil microbiome and production contexts [171]. Contrary to our finding, studies conducted in Nigeria and Ghana showed that 37.5 and 70% of the farmers, respectively, were employing cover crops in their cacao gardens [167, 172]. Nevertheless, cover crops play a crucial role in protecting the soils from erosion and temperature fluctuations, enhancing organic matter content, facilitating nutrient cycling, improving overall soil quality as well as controlling weeds [173, 174]. Farmers in Uganda should therefore be encouraged to employ cover crops in their cacao gardens as one of the recommended Good Agronomic Practices (GAPs), particularly, in young cacao gardens [75].

**Table 11** Percentage of cacao gardens with cover crops observed in the three major cacao growing regions of Uganda

| Region | Not practiced | Lowly practiced |
|---|---|---|
| Central | 94.4 | 2.8 |
| Mid-eastern | 100.0 | 0.0 |
| Mid-western | 95.6 | 4.4 |
| Overall mean | 96.6 | 2.6 |

#### *3.3.1. Trenches*

Digging trenches for water harvesting in rain-fed areas can retain the moisture content in the soil longer and enhance the yield of crops [175]. However, results showed that only 12.9% of the cacao gardens sampled in the three major cacao growing region of Uganda had trenches for soil and water conservation (Table 12). This finding supports earlier studies conducted in Ghana which showed that only 15.5% of the farmers had dug trenches in their cacao gardens [176]. Similarly, [177] reported that only 11 and 13% of the farmers in Bubaare micro-catchment and Maziba sub-catchment, respectively, in Kabale district, south-western Uganda were using trenches in their gardens. Application of trenches is very important for soil conservation as well as improving physical and chemical conditions in the soil, holding surface sediments, nutrients, and nutrients [178]. Trenches also increase soil infiltration and longer retention of moisture in the soil profile [179]. Use of trenches should therefore be emphasized in cacao gardens located in sloppy areas such as Bundibugyo district for soil and water management as well as conservation [180].

**Table 12** Cacao gardens (%) that had trenches as a soil and water conservation method in the three major cocoa growing regions of Uganda

| Region | Not practiced | Lowly | Moderately | Highly |
|---|---|---|---|---|
| Central | 86.1 | 5.6 | 5.6 | 2.8 |
| Mid-eastern | 74.3 | 14.3 | 5.7 | 5.7 |
| Mid-western | 97.8 | 2.2 | 0.0 | 0.0 |
| Overall mean | 87.1 | 6.9 | 3.4 | 2.6 |

*3.3.2. Relationship between key practices and cacao productivity*

Results of the regression analysis showed that the number of cacao pods produced on a tree increased with the level of pruning, de-suckering and stumping (Table 13). However, this was significant ($p \leq 0.05$) for only pruning and stumping. Our finding is in agreement with a number of studies that have reported that pruning increases yield of cacao [e.g. 56, 60, 77, 97, 181, 182, 183]. Similarly, coppicing or stumping has also been reported to increase yields and productivity of cacao [99, 100, 101, 102]. Both practices rejuvenate the cacao trees, improve light penetration and stimulate the development of new buds. They alao remove undesirable branches that compete for nutrients with productive branches, reduce pests and diseases, and enhance nutrient availability, ultimately boosting flowering and pod production [56, 60, 77, 97. 98]. There is therefore a need to sensitize the cacao farmers on rejuvenation and rehabilitation of their gardens to increase cacao bean yield which will improve their standard of living and poverty reduction [63, 108].

On the other hand, the number of pods on a cacao tree decreased with the age and plant density of the trees but not significantly ($p \geq 0.05$). Similarly, [183] and [184] reported a non-significant ($R^2$= 0.004, $p>0.05$) relationship between cacao yield and the age of the plantations. This could in part be attributed to the fact that yield performance behaves as a normal curve with respect to tree age [184, 185]. For example, [186, 187], reported that the highest cacao yield was observed in plantations with young trees but as the tree reached 17-30 years, yields started declining [185, 188]. Cacao yields generally decrease with age of the tree due to a number of factors such as declining tree vigor [151, 189, 190, 191] and soil fertility [192, 193]. Old cacao trees also have a higher risk of contracting pests and diseases [31, 194].

Results further showed that the number of pods decreased with increasing plant density but, not significantly ($R^2$=-1.09, p=0.2743). The same observation was made by [34] in Bokito, central Cameroon and these authors attributed this to the low variability of both variables. Increasing the density of the cacao trees offers competition for nutrients, water, sunlight and rooting space [195, 196], leading to slower vegetative growth and reduction in pod production [197]. This competition may also reduce cacao tree resilience under extreme drought and heat [198].

**Table 13** Relationship between the number of pods and the level of application of the different agronomic practices on cacao in the three major cacao growing regions of Uganda

| Variable | DF | Parameter estimate | Standard error | t-value | P value |
|---|---|---|---|---|---|
| Intercept | 1 | 10.15639 | 1.36642 | 7.43 | <.0001 |
| Pruning | 1 | 1.04343 | 0.49679 | 2.10 | 0.0359 |
| Stumping | 1 | 9.27435 | 1.15633 | 8.02 | <.0001 |
| De-suckering | 1 | 1.50383 | 1.07115 | 1.40 | 0.1606 |
| Age | 1 | -0.30231 | 0.25762 | -1.17 | 0.2408 |
| Plant density | 1 | -0.00092592 | 0.00084660 | -1.09 | 0.2743 |

## 4. Conclusion

Our study investigated farmers' agronomic practices in the three major cocoa growing regions of Uganda. Majority of the cacao plants were >20 years old, generally poorly managed, with low numbers of pods (13.1 pods per tree). On the other hand, most of the cacao gardens were highly intercropped and under agroforestry systems as well as weeded and mulched. However, only a few of them had cover crops and trenches. Furthermore, regression analysis showed that the number of pods increased with the level of pruning, stumping and de-suckering whereas, it decreased with the age and density of the cacao. This study therefore highlighted the importance of Good Agronomic Practices (GAP's) for increasing the yield of cacao in Uganda.

## Compliance with ethical standards

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### *Disclosure of Conflict of interest*

No conflict of interest to be disclosed.

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